Planetary Atmosphere Modeling and Predictions

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The capability to generate spacecraft frequency predictions which include the refractive bending effects induced during signal passage through a planetary atmosphere is a pivotal element of the DSN Radio Science System. This article describes the current implementation effort to develop planetary atmosphere modeling and prediction capability.

I. Introduction

Prior to the Pioneer Venus Orbiter mission, Radio Science data was obtained during planetary occultations via the use of fixed frequency open loop receivers. The open loop receiver bandwidth was selected so as to encompass the received frequency (f_a) dynamic range (plus uncertainties) during the occultation phase (on the order of 10 KHz to 100 KHz total at S-band level), and the resultant receiver output was recorded in analog form on magnetic tapes. These tapes were shipped to the Compatibility Test Area (CTA 21) where they were digitized and formatted into computer compatible magnetic tape for delivery to the Radio Science experimenters. For the Pioneer Venus Orbiter mission, the large number of occultations (~100) and the large dynamic frequency range (up to 100 KHz at S-band) would result in extremely high processing costs and an excessive amount of manual tape handling, if the occultation data were acquired and processed as in previous missions. In the way of a less costly alternative, the idea was conceived of driving the first local oscillator in the open-loop receiver with the predicted frequency (f_p), and subsequently passing a greatly reduced bandwidth containing the mixed frequency (f_a - f_p)[1] through a narrow filter (on the order of several KHz). The receiver output bandwidth could then be digitized in real time and stored, with transmission of the digitized radio science data to the Network Operations Control Center (NOCC) via High Speed Data Line (HSDL) occurring subsequent to the occultation event.

Since processing costs are approximately proportional to recorded bandwidth, this new system could be expected to greatly decrease processing costs and the manual handling and shipment of a very sizeable number of magnetic tapes. Descriptions of this new system can be found in previous issues of the DSN Progress Report (Refs. 1 and 2), and a detailed description of the new subsystem implementation (the DSS Radio Science Subsystem) which supports this task is planned for a future DSN Progress Report issue.

[1]The Radio Science experimenter recovers the actual frequency by adding back the predicted frequency to the mixed frequency: $(f_a - f_p) + f_p = f_a$.

Pivotal to this new method of acquiring radio science data is the predicted frequency, which must now include the refractive bending of the spacecraft signal as it passes through a planetary atmosphere – in sharp contrast to the standard spacecraft frequency predictions currently available. The present implementation effort to add a planetary atmosphere model to the existing spacecraft frequency prediction capability will hence be the subject of the following sections.

II. Implementation of a Planetary Atmosphere Model Capability

The current method of generating spacecraft frequency predictions begins with the delivery by a Flight Project to DSN Network Operations of a spacecraft Probe Ephemeris Tape (PET). The PET tape is first processed by the Fast Phi-Factor Generator Program (FPGP), which resides on the Xerox Data Systems (XDS) Sigma 5 computer in the NOCC Support Subsystem. The FPGP output is a Polynomial Coefficient Tape (PCT), which contains the station-dependent, frequency-independent spacecraft observables. The PCT is then input to the PREDIK program (also residing on the NOCC Support Subsystem XDS Sigma 5 computer), which produces the final frequency-dependent spacecraft observables.

Early in 1977 a tradeoff study was conducted to determine the optimum method, from an implementation and subsequent operations viewpoint, of developing a planetary atmosphere prediction capability. The method selected was:

(1) The modification of an existing general-purpose navigation software program ("POEAS") to include planetary atmosphere effects and to produce as an output a PCT.

(2) The modification of the PREDIK program to output spacecraft frequency predictions in a form specifically designed for the DSS Radio Science Subsystem.

The POEAS program, which resides on the Univac 1108 computer, will be operated by DSN Network Operations. The required input to the POEAS program is a (spacecraft) state vector, which will thus become the Flight Project – DSN interface when generating "Radio Science" predictions. The standard tracking prediction configuration is compared to the new radio science prediction configuration in Fig. 1. A Radio Science Prediction and "Radio Science Data"[2] flow diagram is presented in Fig. 2.

[2]"Radio Science Data" includes both the recorded open-loop receiver data and the frequency used to drive the programmed (first local) oscillator.

III. POEAS Program Planetary Atmosphere Capability Requirements

The functional requirements in regard to the modification of the POEAS software program to develop a planetary atmosphere modeling capability are as follows:

(1) Planetary atmosphere modeling will be available for at least the following planets and satellites:

(a) Venus
(b) Jupiter
(c) Saturn (including rings)
(d) Callisto
(e) Titan
(f) Uranus

It is a design goal to accommodate all planets and satellites.

(2) An event corresponding to a defined transition time between top of atmosphere and free space will be computed.

(3) Signal level degradation will be computed as an analytic function of available program parameters.

(4) The (spacecraft) virtual earth direction in an inertial coordinate system will be computed.

(5) A user input (run-time control) will be available to allow switching at discrete times between different limb signal exit points for oblate planet occultations.

(6) Spacecraft apparent velocity and acceleration will be computed.

IV. PREDIK Program Planetary Atmosphere Capability Requirements

The functional requirements in regard to the modification of the PREDIK software program to develop a planetary atmosphere prediction capability are as follows:

(1) The PREDIK program will accept a new event flag which corresponds to a defined transition between the top of the atmosphere and free space, and will include the event in the prediction computer printout.

(2) The PREDIK program will contain an algorithm which, beginning with the starting frequency, sequentially

proceeds to select frequencies throughout the user-requested time period, in each case selecting the longest sample output interval, such that:

(a) The maximum difference between the instantaneous predicted frequency and the resulting linearly interpolated frequency over the interval will be less than Δf.

(b) Δf will be a user input.

(c) Δf will be restricted to $1 \text{ Hz} \leqslant \Delta f \leqslant 10{,}000 \text{ Hz}$ (S-band).

(3) The user will have the (input) capability to switch the prediction output at discrete times between tracking modes:

(a) D1 (one-way)

(b) D2 (two-way)

(c) D3.XX (three-way with station XX)

(4) The basic output of the PREDIK program will consist of time-tagged S-band frequencies at the proper digitally controlled oscillator (DCO) level (~46 MHz):

(a) The output sample interval will be variable, but subject to a minimum output sample interval of one second.

(b) Samples will be output on the even second.

(5) The PREDIK program will contain an algorithm for the purpose of verifying correct transmission between PREDIK program output and input to the CTA 21 and DSS Radio Science Subsystems.

(6) Whenever the output sample interval is one second, the PREDIK program will output the maximum difference between the instantaneous predicted frequency and the resulting linearly interpolated frequency over the interval.

(7) The user will have the capability to select a time subinterval (t_1, t_2) for which there may be specified starting (t_1), ending (t_2) and several discrete interior $(t_1 < t < t_2)$ frequencies. Exterior to the subinterval, the automatic algorithm will apply.

V. Planned Implementation Schedule

The planned implementation schedule to meet the Pioneer Venus and Voyager mission requirements is as follows:

(1) POEAS transfer to operations:

(a) April 1, 1978 – Venus capability only

(b) September 1, 1978 – full capability

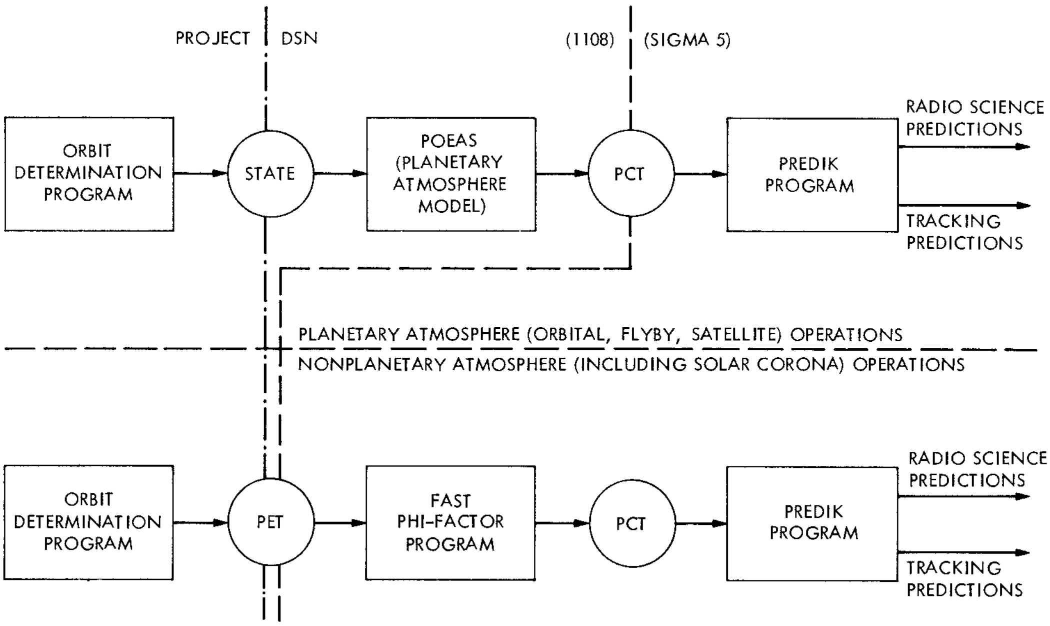
(2) PREDIK transfer to operations:

April 1, 1978 – full capability

References

1. Miller, R. B., "Pioneer Venus 1978 Mission Support," in *The Deep Space Network Progress Report 42-38*, Jet Propulsion Laboratory, Pasadena, California, April 15, 1977.

2. Mulhall, B. D. L., "DSN Radio Science System Description and Requirements" in *The Deep Space Network Progress Report 42-39*, Jet Propulsion Laboratory, Pasadena, California, June 15, 1977.



LEGEND:

PCT = POLYNOMINAL COEFFICIENT TAPE
PET = PROBE EPHEMERIS TAPE
STATE = STATE VECTOR

Fig. 1. Project/DSN prediction interface

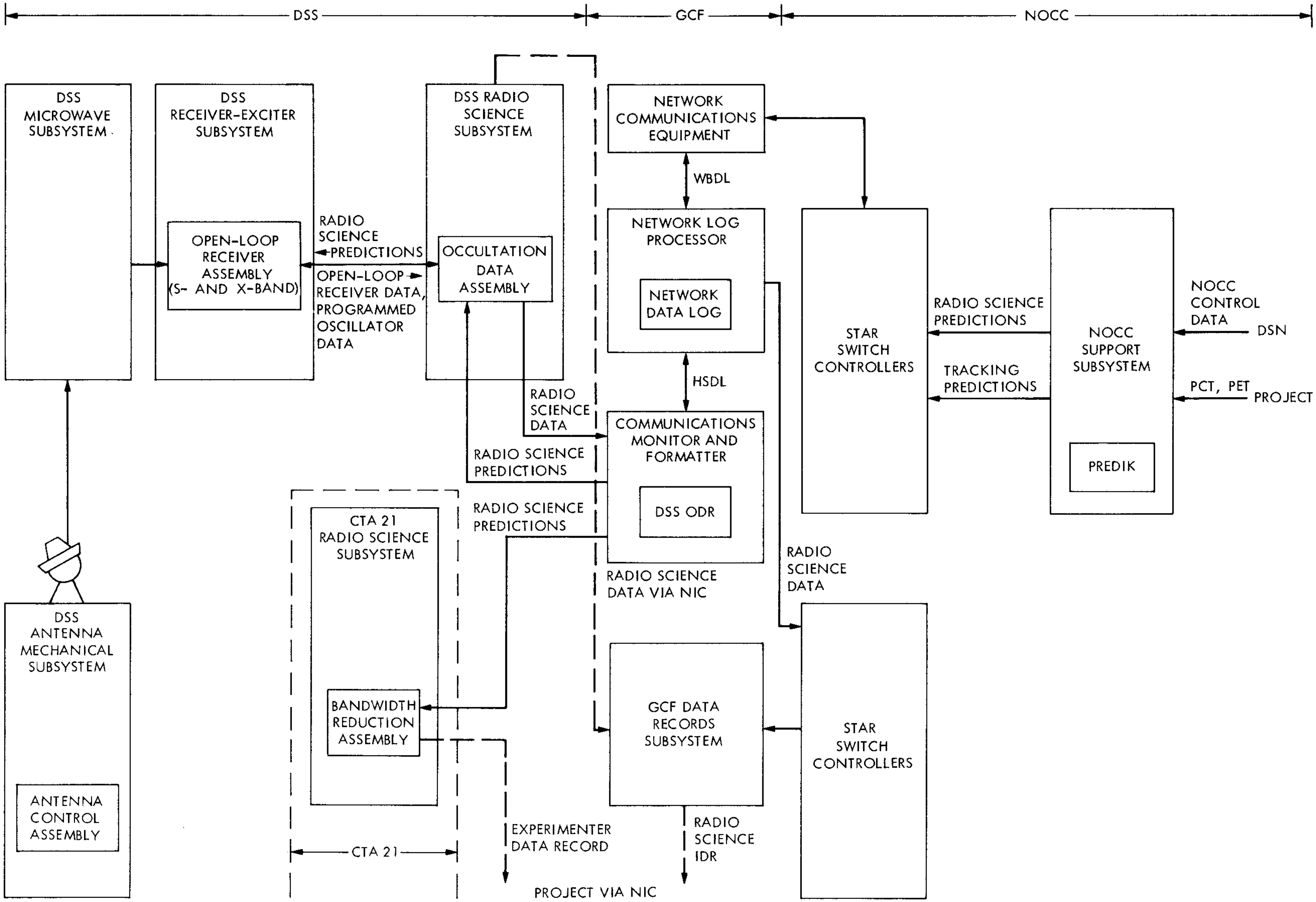


Fig. 2. Planetary atmosphere predictions data flow